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FIDME: Forestry Investment Decisions Made Easy

Bijan Payandeh and J.E. Field

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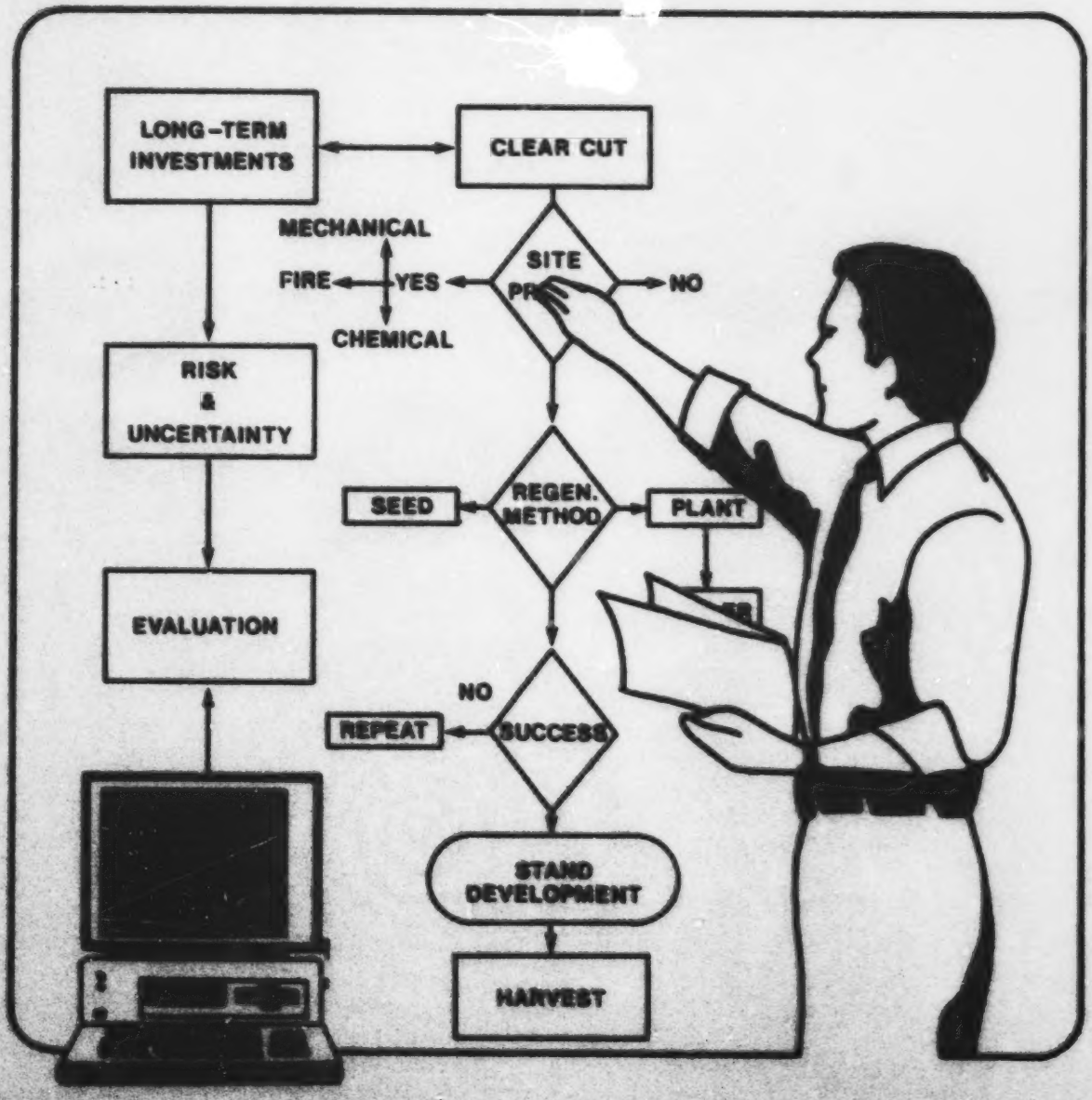

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and

J.E. FIELD

GREAT LAKES FOREST RESEARCH CENTRE

CANADIAN FORESTRY SERVICE

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ABSTRACT

This report discusses briefly the main problems associated with evaluating long-term forestry investments involving risk and uncertainty. Possible means of compensating for risk and uncertainty, including the use of subjective probability as employed in modern decision theory, are also described. A computer model ("FIDME") developed to evaluate such investments is then described. With this model, up to four investment alternatives may be compared by using any one of the following four criteria: 1) cost effectiveness, 2) benefit:cost ratio, 3) present net worth, and 4) internal rate of return. The input estimates for the model may be expressed in the form of either point or subjective probability estimates. Simulated results will provide the probability that one forestry investment might differ from others. Therefore, the forest manager will be able to choose, with a known degree of confidence, between investment alternatives. Four examples and model sensitivity are discussed briefly.

RÉSUMÉ

Les auteurs traitent rapidement des principales difficultés de l'évaluation des investissements à long terme dans les entreprises à risques en foresterie. Ils décrivent les moyens avec lesquels on peut pallier le risque et l'incertitude, y compris par le recours à la probabilité subjective de la théorie moderne de la décision, puis le modèle "FIDME", mis au point pour évaluer de tels investissements. Grâce à ce modèle informatisé, on peut comparer jusqu'à quatre options d'investissement en utilisant n'importe lequel des quatre critères suivants: (1) rentabilité; (2) rapport avantages/coûts; (3) valeur nette actuelle, et (4) taux de rendement interne. Les données estimatives d'entrée peuvent s'exprimer sous la forme d'estimations de la probabilité, ponctuelles ou subjectives. Les résultats de la simulation donnent la probabilité qu'un investissement diffère des autres. L'aménagiste pourra donc choisir, avec un degré connu de confiance, parmi les options d'investissement. Quatre exemples et la sensibilité du modèle font l'objet d'une courte discussion.

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INTRODUCTION

Forest renewal is the most important problem facing forest managers in Canada. Because of the Canadian wood supply situation, federal and provincial agencies and the forest industry are going to have to invest increasingly large sums of money annually in forest renewal. Owing to the long-term nature of such investments, they are subject to risk and uncertainty.

In statistical decision theory, a distinction is made between risk and uncertainty. Risk situations are defined as those in which the probabilities of the outcomes are known or can be estimated. Uncertain situations are defined as those in which probabilities cannot be determined for the outcomes. No such distinction between risk and uncertainty will be made here. Generally, the greater the dispersion of the cash flow estimates, the greater the risk. What will the average price of a cubic metre of black spruce pulpwood be in 50 years? Most managers would say truthfully, "I don't know". However, investment decisions must be made today on the basis of uncertain future costs and returns. Even though the future stumpage price is unknown, it may be possible to specify a distribution of future prices. Such estimates are, of course, subjective. They are based on a knowledge of past trends augmented by intuitive feelings about the future.

There are several methods of adjusting for risk in long-term investments. The most common method is to use a risk-adjusted discount rate defined as $r = i+p$, where r is the risk-free rate, i is interest rate and p is a premium for risk. This approach is based on the premise that risky cash flows are worth less today than certain cash flows and must therefore be discounted at a higher rate. There are two problems associated with the use of the risk-adjusted discount rate. First, it assumes that risk is compounding over time. Second, there is no real basis for choosing the appropriate adjustment factor.

An accepted method of adjusting for uncertainty is the use of certainty-equivalent coefficients. A certainty-equivalent coefficient transforms an uncertain cash flow into an equivalent certain amount. A certainty-equivalent coefficient for period t is defined as α_t, where $0 \leq \alpha_t \leq 1$. A certainty-equivalent coefficient of 1 implies that the cash flow is risk-free. A certainty-equivalent coefficient of 0 implies the cash flow is so risky that it has no value. The main problem with this method is, of course, that of assigning specific values to the coefficients.

Another way to cope with risk and uncertainty involves the use of subjective probability distributions. This method recognizes that the basic cause of risk is variability in the expected future cash flows. Subjective probability estimates may be used not only to account for risk and uncertainty, but also to quantify an expert's opinion augmented by intuitive feelings about the future outcomes. Several probability distribution functions such as Normal, Gamma, Beta and Weibull have been used for this purpose (cf. Schwitzer 1968, Payandeh and Tucker 1975, Payandeh and Field 1978).

Because of the long-term nature of the forest renewal investments and the risk and uncertainty associated with them, it is essential that they be

chosen from the most promising alternatives possible. To evaluate and screen investment alternatives with relative ease and greater precision, forest managers need a technique that not only enables them to predict the rates of return but also indicates the likelihood of their being achieved. This paper briefly describes a computer simulation model developed for comparing the relative economic desirability of various forestry investments subject to risk and uncertainty--particularly those related to forest renewal activities.

BRIEF DESCRIPTION OF THE MODEL

The model is named "FIDME", an acronym for "Forestry Investment Decisions Made Easy". It is an extension of the earlier model "REGEN" (Payandeh and Field 1978). FIDME is basically a very flexible "economic evaluator" or "cash flow analyzer" for comparing long-term forest renewal investment alternatives. Any set of forest regeneration systems and various silvicultural treatments and management actions associated with them may be compared as long as the differences among such regeneration systems can be expressed in terms of differences in costs, probability of success, stocking level, rotation age, expected yield, future prices, etc. The model contains no assumptions[1] about stand dynamics and growth as it deals with economic analysis only. However, the input estimates may implicitly reflect the overall assumptions made by the user about the interaction of economic, physical and biological factors affecting various regeneration systems.

The model is an easy-to-use simulation model that will assist forest managers, policy makers and administrators in making rational economic decisions on various forest renewal investment alternatives. For example, it may be used to compare up to four forest renewal systems based on any one of the four economic criteria[2] of: 1) cost effectiveness, 2) benefit:cost ratio, 3) present

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1 The only assumptions made in the model with respect to the cost of stand establishment are that an area or a site may be regenerated up to a maximum of three times per site preparation and that it may be site prepared up to a maximum of three times to produce a successful regeneration.

2 Definitions of these criteria may be found in most forest management/economics texts. 1) Cost-effectiveness is based on future cost/unit of volume (output). It does not require future price estimation and does not account for the difference in the quality of the products. A forest renewal with the lowest future cost/unit of volume would be the most economical one on this basis. 2) Benefit:cost ratio is the ratio of the sum of discounted returns to the sum of discounted costs. The alternative with the highest benefit:cost ratio would be the most economical one. 3) Present net worth is the difference between the sum of discounted returns and discounted costs. The alternative with the largest present net worth would be the most economical one. Benefit:cost ratio and present net worth are closely related and both require an assumed discount rate and estimation of future prices. 4) Internal rate of return is a discount rate at which the discounted returns and costs are equal or the present net worth is zero. This criterion does not require an assumed discount rate, but it does require estimates of future prices.

net worth, and 4) internal rate of return (cf. Lundgren 1973, Payandeh 1977, Foster and Brooks 1983).

Each forest renewal system or investment alternative may consist of one or more of the following types of costs and returns:

1. Initial costs: a) land value, i.e., purchase price or market value of land/unit area

   b) preparation costs, e.g., site preparation, access road construction, etc.

   c) establishment costs, e.g., cost of planting, cost of seeding, etc.

2. Annual costs, e.g, property tax, road maintenance, forest protection and rent, etc.

3. Periodic costs, e.g., cost of fertilization, thinning, spraying, etc.

4. Final costs, e.g., harvesting and/or transportation costs (total cost of wood delivered to the mill).

5. Terminal cost, e.g., legal fees and/or other costs associated with the sale of the land, etc.

The investment returns might be one or more of the following types:

1. Annual returns, e.g., user fees for hunting or fishing, etc.

2. Periodic returns, e.g., proceeds from commercial thinning, etc.

3. Final return, e.g., revenue from final harvest at rotation age.

4. Terminal return, i.e., future market value of the land/unit area.

5. Final product price, i.e., future price/unit for the final products.

In the model up to four products, e.g., pulpwood, pole timber, saw timber and veneer, and four prices may be specified. The input for the model may be in the form of point estimates (when the input estimate is known or may be determined free of error) or subjective or judgmental probability estimates (cf. Englehard and Anderson 1983, Yared 1983).

Like its predecessor, "FIDME" uses mainly subjective or judgmental estimates provided by the forest manager and based on his experience with a given forest renewal system. Such estimates are used in the model to generate appropriate probability distributions via the Weibull function. Each distribution so generated will represent the frequency distribution of a given cost, expected stocking level, future yield or product prices for any reforestation system that the forest manager wishes to specify.

The model is designed so that it simulates all forestry investments in question in a parallel manner. For example, in the case of comparing, say, three regeneration systems, the area(s) or site(s) characterized by the input variables are reforested by the regeneration systems enough times to produce a desired number, e.g., 300, of successful reforestations or "successes". All costs and returns associated with a successfully regenerated stand (including the cost of regeneration failures, if any) are properly analyzed, i.e., compounded or discounted depending on criteria used.[3] Finally, a frequency distribution of the final results, expressed by any of the four economic criteria mentioned earlier, for each reforestation system is constructed, and from this the results can be obtained for a desired probability level.

Because various investment alternatives are simulated in a parallel manner to produce an equal number of "successes" and since the results are calculated on per unit output or area, the results of different operations are directly comparable. That is, all differences in costs (initial, annual, periodic and final costs), probability of success, stocking level, rotation age, expected returns (annual, periodic, final and terminal returns), and future product prices, etc., are accounted for.

FIDME is written in structured FORTRAN 77 and may be run interactively or in a batch mode. Input for the model may be entered from the terminal or read from an input file. The output similarly may be directed to the terminal or the line printer.

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[3] For example, present net worth is calculated as:

$$PNW = \frac{V_1(1+i)^1}{(1+r)^1} + \cdots + \frac{V_j(1+i)^j}{(1+r)^j} + \cdots + \frac{V_n(1+i)^n}{(1+r)^n} \qquad (1)$$

where: PNW = present net worth in $/unit area,
V_j = the cost or return in the j^{th} year,
i = average inflation rate/year,
r = average interest rate/year,
n = rotation age.

Benefit:cost ratio is calculated from the above formula as the ratio of the sum of discounted returns over the discounted costs.

Internal rate of return is calculated by iterative solution of equation (1) above to find a value for r which equates PNW to zero.

For cost-effectiveness criteria, future costs per unit volume are derived from the sum of future costs at rotation age.

EXAMPLES OF MODEL APPLICATION

The application of the model is demonstrated here by describing four examples in some detail. Although attempts were made to use current cost estimates where possible, the main objective of the examples is to show the model capability and flexibility and not to recommend one regeneration system over another. The input estimates for the examples were obtained mainly from the recent literature (e.g., Mullin and Howard 1973, Anon. 1974, Waldron 1974, Olson et al. 1978, Bradley and Lothner 1982) and from several forest managers from the Ontario Ministry of Natural Resources.[4]

In the first example the cost-effectiveness of pulpwood production from planted and seeded jack pine (*Pinus banksiana* Lamb.) is compared. This example may apply to a large area of clearcut on crown land in Ontario most suitable for growing jack pine. The main question facing the forest manager in this case would be whether to seed or to plant the area. The forest manager knows from experience that the cost of planting such an area is much greater than that of seeding. On the other hand, the chance of success in regeneration with planting is considerably better than that with seeding. He also knows that jack pine seeded stands require at least one precommercial thinning at about 15 years of age. He has to assume as well that the rotation age for seeded stands would be up to 10 years longer than that for planted stands or, what amounts to the same thing, that the yield from seeded stands would be less than that from planted stands for the same rotation age.

Input estimates for the first example are summarized in Table 1. This example does not include input estimates for annual and liquidation costs and annual, periodic and terminal returns since such costs and returns do not usually apply to crown land. In the case of planting jack pine, bare-root stock is assumed to be planted at a rate of about 1900 trees/ha.

Table 1 provides subjective estimates of the cost per hectare of light mechanical site preparation required for planting jack pine as: a) low estimate = $110.00, b) high estimate = $140.00, c) the probability that the cost of site preparation will be lower than the low estimate = 0.10, d) the probability that the cost of site preparation for planting jack pine will be lower than the high estimate = 0.95, and e) the minimum cost of light mechanical site preparation = $100/ha. Similarly, the three subjective estimates of the cost per hectare of heavy mechanical site preparation required for seeding jack pine, together with the high and low probabilities, are: $250.00, $320.00, 0.10, 0.95 and $230.00/ha.

Subjective estimates of the cost per hectare of planting jack pine bare-root stock are as follows: a) low estimate of $250.00, b) high estimate of $350.00, c) the probability that the cost of planting jack pine will be less than the low estimate = 0.05, d) the probability that planting jack pine will be less than the high estimate = 0.95, and e) the absolute minimum cost of planting

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[4]Calvert, R. 1984. Ontario Ministry of Natural Resources, Regional Office, Timmins, Ont. (pers. comm.).

Table 1. Input estimates of Model "FIDME" for comparing the cost-effectiveness of planting and seeding jack pine.

Input estimate	Regen. method	Point estimate ($/ha)	Subjective estimates				
			Low ($/ha)	High ($/ha)	Prob. low	Prob. high	Minimum ($/ha)
Site preparation[a]	plant.	--	110	140	0.10	0.95	100
	seed.	--	250	320	0.10	0.95	230
Establishment[a]	plant.	--	250	350	0.05	0.95	225
	seed.	--	30	60	0.10	0.90	20
Stocking standard	plant.	--	0.45	0.65	--	--	--
	seed.	--	0.45	0.65	--	--	--
Expected stocking	plant.	--	0.40	0.95	0.10	0.90	0.35
	seed.	--	0.20	0.95	0.10	0.80	0.00
Periodic cost[b]	plant.	--	--	--	--	--	--
	seed.	--	75	300	0.05	0.80	50
Product #1 yield (m^3/ha)	plant.	--	200	300	0.10	0.95	150
	seed.	--	150	250	0.10	0.95	120
Product #1 price ($/$m^3$)[c]	plant.	--	1.5	2.00	0.10	0.90	1.00
	seed.	--	1.5	2.00	0.10	0.90	1.00

Economic criteria cost-effectiveness
Rotation age 70 years
Interest rate 10%
Inflation rate 5%
Number of iterations 300
Random number generator starter (seed) 13345

[a] A maximum is required for the number of scarifications per site beyond which the site is considered abandoned because of repeated unsuccessful regeneration. Also, a maximum is required for the number of regeneration operations per site preparation beyond which the area will not be rescarified. Such maxima for the above examples were 2 and 3 for both regeneration systems.

[b] For periodic costs and returns a start, an interval and an end year are required.

[c] The period for which future prices are estimated, e.g., 5, 10 or 20 years, is required beyond which future prices are projected on the basis of the inflation rate.

jack pine bare-root stock = $225.00/ha. Likewise, subjective estimates of the cost per hectare of seeding jack pine are: a) low estimate = $30.00, b) high estimate = $60.00, c) the probability that the cost of seeding jack pine will be lower than the low estimate = 0.10, d) the probability that the cost of seeding jack pine will be less than the high estimate = 0.90, and e) the absolute minimum cost of seeding jack pine = $20/ha. Stocking standards are specified as interval estimates and are the same for both regeneration systems. In the simulation process if a regeneration system results in a stocking level of less than .45, it will be considered a failure and the site will be replanted. If a regeneration method results in a stocking of .65 or better, it will be considered a successful regeneration.

Subjective estimates of the expected stocking levels for planting jack pine are given as: a) low estimate = 0.40, b) high estimate = 0.95, c) the probability that stocking will be lower than the low estimate = 0.10, d) the probability that stocking will be lower than the high estimate = 0.90, and e) the absolute minimum stocking for planting jack pine = 0.35. The five subjective estimates for the expected stocking level for seeding jack pine are: a) low estimate = 0.20, b) high estimate = 0.95, c) the probability that stocking will be less than the low estimate = 0.10, d) the probability that stocking will be less than the high estimate = 0.80, and e) the absolute minimum expected stocking level from seeding jack pine = 0.00.

A subjective estimate of the cost per hectare of precommercial thinning for seeded jack pine is given as a periodic cost (at age 15 years): a) low estimate = $75.00, b) high estimate = $300.00, c) the probability that the cost of thinning will be lower than the low estimate = 0.05, d) the probability that the cost of thinning will be lower than the high estimate = 0.80, and e) the absolute minimum cost of thinning = $50.00/ha.

In the first three examples, it is assumed that the final yield will be harvested as a single product in the form of pulpwood. Subjective estimates of the final yield per hectare for planted jack pine are: a) low estimate = 200 m^3, b) high estimate = 300 m^3, c) the probability that the yield of pulpwood per hectare for planted jack pine will be less than the low estimate = 0.10, d) the probability that the yield/ha will be less than the high estimate = 0.95, and e) the absolute minimum yield of pulpwood = 150 m^3/ha. Similarly, estimates of yield/ha at rotation age for the seeded jack pine stand are: a) low estimate = 150 m^3, b) high estimate = 250 m^3, c) the probability that yield/ha from seeded jack pine will be less than the low estimate = 0.10, d) the probability that the yield estimate will be less than the high estimate = 0.95, and e) the absolute minimum yield of pulpwood from seeded jack pine = 120 m^3/ha. Future (i.e., 10 years hence for the examples given here) pulpwood prices used are: a) low estimate = $1.50/$m^3$, b) high estimate = $2.00/$m^3$, c) the probability that the pulpwood price will be less than the low estimate = 0.10, d) the probability that the jack pine pulpwood price will be less than the high estimate = 0.90, and e) the absolute minimum future pulpwood price = $1.00/$m^3$. Other input estimates for the first example are given at the bottom of Table 1.

In the second example, two methods of planting jack pine are compared according to the benefit:cost ratio criterion. This example may also apply to large cutover areas of crown land in Ontario most suitable for jack pine regeneration. It is assumed here that the main differences between planting bare-root and container stock of jack pine are that container tree seedlings require a more intensive and therefore more expensive site preparation than bare-root stock, but that the cost of planting containerized seedlings is considerably less than that of planting bare-root stock. For this example, it is also assumed that the expected stocking from containerized seedlings is higher than that from bare-root stock.

Input estimates for the second example are summarized in Table 2. It is noted that the input estimates for planting bare-root jack pine are identical to those in Table 1. Subjective estimates of cost of intensive mechanical site preparation required for planting jack pine containerized seedlings are given as: a) low estimate = $250.00, b) high estimate = $320.00, c) the probability that cost of site preparation will be less than the low estimate = 0.10, d) the probability that cost of site preparation will be less than the high estimate = 0.95, and e) the absolute minimum cost for heavy mechanical site preparation = $230.00/ha. Similarly, the three subjective estimates of the cost of planting jack pine containerized tree seedlings, together with the high and low probabilities, are: $140.00, $230.00, 0.10, 0.95 and $130.00/ha. As mentioned above, the expected stocking from planting containerized seedlings is assumed to be higher than that from planting bare-root jack pine stock. These are given as: a) low estimate = 0.45, b) high estimate = 0.95, c) the probability that the expected stocking from containerized seedlings will be less than the low estimate = 0.05, d) the probability that the expected stocking from containerized seedlings will be less than the high estimate = 0.95, and e) the absolute minimum expected stocking from jack pine containerized seedlings = 0.40. Other input estimates including the volume yield of pulpwood at a rotation age of 70 years and the estimated future price of pulpwood are assumed to be the same for the two regeneration systems and equal to those for planting jack pine mentioned earlier and indicated in Table 2.

In the third example, three regeneration systems are compared on the basis of the present net worth criterion. This example may also apply to large cutover areas of crown land in Ontario. It is assumed that three sites are involved here, the first being most suitable for growing jack pine (e.g., a sandy, flat site), the second being most suitable for growing black spruce *(Picea mariana* [Mill.] B.S.P.) (e.g., a peatland site), and the third being most suitable for growing white spruce *(P. glauca* [Moench] Voss) (e.g., an upland site). It is further assumed that bare-root stock will be planted in the case of jack pine and black spruce which require light mechanical site preparation, and containerized tree seedlings will be used in the case of white spruce which requires heavy mechanical site preparation. The main differences in site productivity between the three areas are reflected in the rotation ages used and estimates of final yield for the three regeneration systems being compared.

Table 2. Input estimates of Model "FIDME" for economic comparison of planted jack pine with bare-root stock and containerized seedlings.

Input estimate	Regen. method	Point estimate ($/ha)	Subjective estimates				
			Low ($/ha)	High ($/ha)	Prob. low	Prob. high	Minimum ($/ha)
Site preparation[a]	bare	--	110	140	0.10	0.95	100
	cont.	--	250	320	0.10	0.95	230
Establishment[a]	bare	--	250	350	0.05	0.95	225
	cont.	--	140	230	0.10	0.95	130
Stocking standard	bare	--	0.45	0.65	--	--	--
	cont.	--	0.45	0.65	--	--	--
Expected stocking	bare	--	0.40	0.95	0.10	0.95	0.35
	cont.	--	0.45	0.95	0.05	0.95	0.40
Product yield (m^3/ha)	bare	--	200	300	0.10	0.95	150
	cont.	--	200	300	0.10	0.95	150
Product price[b] ($/$m^3$)	bare	--	1.50	2.00	0.10	0.90	1.00
	cont.	--	1.50	2.00	0.10	0.90	1.00

Rotation age 70 years
Interest rate 10%
Inflation rate 5%
Number of iterations 300
Random number generator starter (seed) 35

[a] A maximum is required for the number of scarifications per site beyond which the site is considered abandoned because of repeated unsuccessful regeneration. Also, a maximum is required for the number of regeneration operations per site preparation beyond which the area will not be rescarified. Such maxima for the above examples were 2 and 3 for both regeneration systems.

[b] The period for which future prices are estimated, e.g., 5, 10 or 20 years, is required beyond which future prices are projected on the basis of the inflation rate.

Input estimates for the third example are summarized in Table 3. It is noted that the input estimates for planting jack pine bare-root stock are identical to those in Table 1. Subjective estimates of the cost of site preparation and planting are assumed to be the same for both planted jack pine and black spruce bare-root stock as given in Table 3. Estimates of the cost of site preparation for planted white spruce containerized seedlings are given: a) low estimate = $250.00, b) high estimate = $320.00, c) the probability that the cost of site preparation will be less than the low estimate = 0.10, d) the probability that the cost of site preparation will be less than the high estimate = 0.95 and e) the absolute minimum cost of site preparation = $230.00/ha. Similarly, the three subjective estimates of the cost of planting containerized white spruce seedlings, together with the high and low probabilities, are: $150.00, $230.00, 0.10, 0.95 and $130.00/ha.

Stocking standards for the three regeneration systems specified by interval estimates are the same as in the first two examples (low = 0.45 and high = 0.65). The five subjective estimates of the expected stocking for the three regeneration systems are 0.40, 0.95, 0.10, 0.90 and 0.35 for planted jack pine, 0.35, 0.90, 0.10, 0.95 and 0.30 for planted black spruce and 0.45, 0.95, 0.05, 0.95 and 0.40 for planted white spruce containerized seedlings, respectively. Subjective estimates for the final yield for the three regeneration systems are 200 m^3, 300 m^3, 0.10, 0.95 and 150 m^3/ha for planted jack pine; 180 m^3, 230 m^3, 0.10, 0.95, and 150 m^3/ha for planted black spruce; and 280 m^3, 350 m^3, 0.10, 0.90, and 250 m^3/ha for planted white spruce containerized seedlings. Future (i.e., 10 years hence for these examples) pulpwood prices are the same for the three regeneration systems as in Tables 1 and 2.

Input estimates for the fourth example are summarized in Table 4. This example compares the relative economic desirability of three alternative methods of growing timber for pulpwood and/or sawlog production with that of Christmas tree production on three different sites. This example may apply to privately owned forest lands and is presented here mainly to demonstrate the flexibility of the model application. The objective of such an economic comparison might be to rank the areas for investment by the landowner on the basis of the expected rate of return from each alternative investment.

The initial cost (i.e., the market value of the land in $/ha) for the three sites for planting jack pine, black spruce and Scots pine (*Pinus sylvestris* L.) are assumed to be $100.00, $25.00 and $500.00/ha, respectively. Since the present value of land is either known or subject to minor variability, point estimates are used in this case. The difference between the initial cost of the three sites is presumed to reflect the difference in value of the land resulting from differences in site quality, location, accessibility and other factors affecting the market value of forest lands. Subjective estimates of the cost of site preparation and regeneration establishment for planted jack pine and black spruce are identical to those in the previous example. The Scots pine plantation, however, is assumed to require intensive site preparation similar to that required for planting of containerized seedlings, as given in Tables 2 and 3.

Table 3. Input estimates of Model "FIDME" for economic comparison of three regeneration systems (planted jack pine and black spruce bare-root stock and white spruce containerized seedlings) on three different sites.

Input estimate	Regen. method[c]	Point estimate $/ha	Subjective estimates				
			Low ($/ha)	High ($/ha)	Prob. low	Prob. high	Minimum ($/ha)
Site preparation[a] ($/ha)	Pj BR	--	110	140	0.10	0.95	100
	Sb BR	--	110	140	0.10	0.95	100
	Sw cont.	--	250	320	0.10	0.95	230
Establishment[a] ($/ha)	Pj BR	--	250	350	0.10	0.95	225
	Sb BR	--	250	350	0.10	0.95	225
	Sw cont.	--	150	230	0.10	0.95	130
Stocking standard	Pj BR	--	0.45	0.65	--	--	--
	Sb BR	--	0.45	0.65	--	--	--
	Sw cont.	--	0.45	0.65	--	--	--
Expected stocking	Pj BR	--	0.40	0.95	0.10	0.90	0.35
	Sb BR	--	0.35	0.90	0.10	0.95	0.30
	Sw cont.	--	0.45	0.95	0.05	0.95	0.40
Product #1 yield (m^3/ha)	Pj BR	--	200	300	0.10	0.95	150
	Sb BR	--	180	230	0.10	0.95	150
	Sw cont.	--	280	350	0.10	0.90	250
Product #1 price[b] ($/$m^3$)	Pj BR	--	1.50	2.00	0.10	0.90	1.00
	Sb BR	--	1.50	2.00	0.10	0.90	1.00
	Sw cont.	--	1.50	2.00	0.10	0.90	1.00
Rotation age (years)	Pj BR	70	--	--	--	--	--
	Sb BR	90	--	--	--	--	--
	Sw cont.	80	--	--	--	--	--

Interest rate 12%
Inflation rate 5%
No. of iterations 300
Random number generator starter (seed) 135

[a] A maximum is required for the number of scarifications per site beyond which the site is considered abandoned because of repeated unsuccessful regeneration. Also, a maximum is required for the number of regeneration operations per site preparation beyond which the area will not be rescarified. Such maxima for the above examples were 2 and 3 for both regeneration systems.

[b] The period for which future prices are estimated, e.g., 5, 10 or 20 years, is required beyond which future prices are projected on the basis of the inflation rate.

[c] Pj BR = jack pine bare-root, Sb BR = black spruce bare-root, Sw cont. = white spruce containerized stock.

Table 4. Input estimates of Model "FIDME" for economic comparison of three forestry investment alternatives (planted jack pine and black spruce bare-root stock for pulpwood and/or sawlog production and planted Scots pine for Christmas tree production) on three privately owned sites.

Input estimate	Invest. method[e]	Point estimate ($/ha)	Subjective estimates				
			Low ($/ha)	High ($/ha)	Prob. low	Prob. high	Minimum ($/ha)
Initial cost ($/ha)	Pj BR	100	--	--	--	--	--
	Sb BR	25	--	--	--	--	--
	Ps Ch	500	--	--	--	--	--
Site preparation[a] ($/ha)	Pj BR	--	110	140	0.10	0.95	100
	Sb BR	--	110	140	0.10	0.95	100
	Ps Ch	--	250	320	0.10	0.95	230
Establishment[a] ($/ha)	Pj BR	--	250	350	0.05	0.95	225
	Sb BR	--	250	350	0.05	0.95	225
	Ps Ch	--	250	350	0.05	0.95	225
Stocking standard	Pj BR	--	0.45	0.65	--	--	--
	Sb BR	--	0.45	0.65	--	--	--
	Ps Ch	--	0.45	0.65	--	--	--
Expected stocking	Pj BR	--	0.40	0.95	0.10	0.90	0.35
	Sb BR	--	0.35	0.90	0.10	0.95	0.30
	Ps Ch	--	0.80	0.95	0.10	0.95	0.50
Annual cost ($/ha)	Pj BR	4	--	--	--	--	--
	Sb BR	1	--	--	--	--	--
	Ps Ch	20	--	--	--	--	--
Periodic cost #1[b] ($/ha)	Pj BR	--	75	300	0.05	0.80	50
	Sb BR	--	--	--	--	--	--
	Ps Ch	--	35	60	0.10	0.90	30
Periodic cost #2[b] ($/ha)	Pj BR	--	75	300	0.05	0.80	50
	Sb BR	--	--	--	--	--	--
	Ps Ch	--	120	150	0.10	0.90	100
Liquidation cost ($/ha)	Pj BR	--	--	--	--	--	--
	Sb BR	--	--	--	--	--	--
	Ps Ch	50	--	--	--	--	--
Annual return[c] ($/ha)	Pj BR	4	--	--	--	--	--
	Sb BR	--	--	--	--	--	--
	Ps Ch	--	--	--	--	--	--

(continued)

Table 4. Input estimates of Model "FIDME" for economic comparison of three forestry investment alternatives (planted jack pine and black spruce bare-root stock for pulpwood and/or sawlog production and planted Scots pine for Christmas tree production) on three privately owned sites (concluded).

Input estimate	Invest. method[e]	Point estimate ($/ha)	Subjective estimates				
			Low ($/ha)	High ($/ha)	Prob. low	Prob. high	Minimum ($/ha)
Periodic return[b] ($/ha)	Pj BR	--	60	100	0.20	0.80	50
	Sb BR	--	--	--	--	--	--
	Ps Ch	--	--	--	--	--	--
Terminal return ($/ha)	Pj BR	--	--	--	--	--	--
	Sb BR	--	--	--	--	--	--
	Ps Ch	700	--	--	--	--	--
Product #1 (m^3/ha)	Pj BR	--	150	200	0.10	0.95	100
	Sb BR	--	180	230	0.10	0.95	150
(trees/ha)	Ps Ch	--	800	950	0.10	0.90	700
Product #1 price[d] ($/unit)	Pj BR	--	1.50	2.00	0.10	0.90	1.00
	Sb BR	--	1.50	2.00	0.10	0.90	1.00
	Ps Ch	--	3	5	0.10	0.90	2.50
Product #2 (m^3/ha)	Pj BR	--	75	100	0.10	0.95	50
	Sb BR	--	--	--	--	--	--
	Ps Ch	--	--	--	--	--	--
Product #2 price[d] ($/unit)	Pj BR	--	10.00	15.00	0.10	0.90	5.00
	Sb BR	--	--	--	--	--	--
	Ps Ch	--	--	--	--	--	--
Rotation age (years)	Pj BR	70	--	--	--	--	--
	Sb BR	70	--	--	--	--	--
	Ps Ch	10	(analysis carried out for two rotations)				

Interest rate 10%
Inflation rate 5%
Number of iterations 300
Random number generator starter (seed) 1235

[a] A maximum is required for the number of scarifications per site beyond which the site is considered abandoned because of repeated unsuccessful regeneration. Also, a maximum is required for the number of regeneration operations per site preparation beyond which the area will not be rescarified. Such maxima for the above examples were 2 and 3 for both regeneration systems.

[b] For periodic costs and returns a start, an interval and an end year are required.

[c] In the case of annual costs and returns, a start and an end year are required.

[d] The period for which future prices are estimated, e.g., 5, 10 or 20 years, is required beyond which future prices are projected on the basis of the inflation rate.

[e] Ps Ch = Scots pine Christmas trees.

The cost of regenerating Scots pine is assumed to be the same as that of regenerating jack pine and black spruce (see Table 4). Stocking standards for all three regeneration systems are assumed to be the same as in the previous examples. The expected stocking from both planted jack pine and planted black spruce is also assumed to be the same as that given in the previous example. The five subjective estimates of the expected stocking from Scots pine are: a) low estimate = 0.80, b) high estimate 0.95, c) the probability that the expected stocking will be lower than the low estimate = 0.10, d) the probability that the expected stocking will be lower than the high estimate = 0.95, and e) the absolute minimum for expected stocking = 0.50.

The annual costs/ha (i.e., property tax, etc.) are assumed to be $4.00, $1.00 and $20.00/ha/year for the three sites, respectively. It is assumed that the jack pine plantation will be thinned twice (at the ages of 15 and 35 years), the latter being a commercial thinning. The subjective estimates of the cost of both thinnings are assumed to be the same as those given for the first example. No periodic costs are assumed in the case of planted black spruce as indicated in Table 4. The costs of tending the Scots pine plantation are expressed in the form of two periodic costs: one for herbicide application to reduce competing vegetation and the other for pruning and shaping individual trees. It is assumed that herbicide application will begin in the second year and will be repeated every other year until age eight years. Subjective estimates of the cost of spraying (Olson et al. 1979) are: a) low estimate = $35.00, b) high estimate = $60.00, c) the probability that the cost of spraying will be less than the low estimate = 0.10, d) the probability that the cost of spraying will be less than the high estimate = 0.90, and e) the absolute minimum for the cost of spraying = $30.00/ha. It is also assumed that the pruning operation will begin in the first year and will be carried on every year until year 9, one year before harvesting. Table 4 gives the three subjectives estimates of the cost of pruning, together with the high and low probabilities, as $120.00, $150.00, 0.10, 0.90 and $100/ha.

The next input estimate given in Table 4 is the liquidation cost, e.g., commission and legal fees for the sale of land for the Scots pine plantation site ($50.00/ha). It is assumed that the site will be sold following the second rotation, i.e., after 20 years, at $700.00/ha. The annual return, e.g., user's fee for hunting, fishing, picnicking, etc., from the jack pine site is assumed to be $4.00/ha. It is assumed that commercial thinning of the jack pine stand at age 35 years will result in a periodic return as follows: a) low estimate = $60.00, b) high estimate = $100.00, c) the probability that the periodic return will be less than the low estimate = 0.20, d) the probability that the return from commercial thinning will be less than the high estimate = 0.80, and e) the absolute minimum from the periodic return = $50.00/ha.

The final yield from the jack pine plantation is assumed to be in the form of two products: pulpwood and sawlogs. The five subjective estimates of pulpwood production are 150, 200, 0.10, 0.95 and 100 m^3/ha, and those for sawlog production are 75, 100, 0.10, 0.95 and 50 m^3/ha. It is assumed that the final yield from the black spruce plantation will be used as pulpwood only, and the

estimates are the same as in the previous example. The final product from the Scots pine plantation is expressed as the number of Christmas trees harvested per hectare, i.e., a) low estimate = 800, b) high estimate = 950, c) the probability that the number of Christmas trees will be less than the low estimate = 0.10, d) the probability that the number of trees will be less than the high estimate = 0.90, and e) the absolute minimum estimate = 700 Christmas trees/ha. Future (i.e., 10 years hence for this example) pulpwood prices used for the jack pine and black spruce are the same as in the previous examples. The subjective estimates of the future price of Scots pine Christmas trees (on the stump) are: a) low estimate = $3.00, b) high estimate = $5.00, c) the probability that the future price will be less than the low estimate = 0.10, d) the probability that the future price will be less than the high estimate = 0.90, and e) the absolute minimum = $2.50/tree. Finally, the three subjectives estimates of future price of sawlog jack pine, together with the high and low probabilities, are assumed to be $10.00, $15.00, 0.10, 0.90 and $5.00/$m^3$. Other input estimates for the fourth example are given at the bottom of Table 4.

RESULTS (OUTPUT) AND INTERPRETATION

As mentioned earlier the sole purpose of the examples used above and the results described here is to demonstrate the model application and its flexibility, and not to recommend a specific regeneration system. Some of the assumptions made may apply only to hypothetical situations; nevertheless, the examples should serve to demonstrate the capabilities and applications of the model.

Results of the first example are summarized in Table 5. The first column of Tables 5-8 labelled "Probability of exceeding" applies to the remaining columns in these tables. The second row (or line) of Table 5 indicates, for example, that there is a 10% chance that the future cost per m^3 of pulpwood will exceed $84.04 for planted jack pine and $76.06 for seeded jack pine. Conversely, there is a 90% chance that the future cost per m^3 of pulpwood will be equal to or less than these figures for planted and seeded jack pine. The future cost difference between planted and seeded jack pine is given in column 4 of Table 5. Column 4 indicates, for example, that there is a 10% chance that the future cost of a cubic metre of pulpwood from a jack pine seeded stand will be less than that of a jack pine plantation by $7.98. Line 3 of Table 5 indicates that there is a 20% chance that the future cost of pulpwood per cubic metre will exceed $65.94 from jack pine plantations and $67.99 from jack pine seeded stands. Conversely, Table 5 indicates that there is an 80% chance that the future cost per cubic metre will be between $27.50 and $65.94 for pulpwood from jack pine plantations and between $29.32 and $67.99 for pulpwood from seeded jack pine stands. Column 4 of Table 5 also indicates that there is an 80% chance that the future cost per cubic metre of pulpwood from planted jack pine will be less than that from seeded stands by about $1.82 or more.

Table 5. Output of simulator "FIDME" for comparing the cost-effectiveness of pulpwood production from planted and seeded jack pine for a rotation age of 70 years, an interest rate of 10% and an inflation rate of 5%.

Probability of exceeding	Future cost ($/m^3)		Future cost difference ($/m^3)
	Planted jack pine	Seeded jack pine	Planted - seeded jack pine
0.00	236.47	173.39	63.08
0.10	84.04	76.06	7.98
0.20	65.94	67.99	-2.05
0.30	55.17	63.53	-8.36
0.40	49.26	60.38	-11.12
0.50	45.75	56.98	-11.23
0.60	43.67	53.17	-9.50
0.70	41.07	49.86	-8.79
0.80	38.57	46.60	-8.03
0.90	35.92	42.82	-6.91
1.00	27.50	29.32	-1.82

As mentioned earlier, the first example should demonstrate the application of the model in fairly simple situations where two or more regeneration systems are to be compared for a given area (or site) and for the same rotation age. In the above example, the main differences between seeded and planted jack pine are expressed in terms of differences in the cost of site preparation, the cost of stand establishment, expected stocking, thinning requirements and the difference in the final yield. On the basis of the input estimates used for this example, there is less than a 20% chance that seeded jack pine will be a more cost-effective regeneration system than planted jack pine. On the other hand, there is more than an 80% chance that planted jack pine will be a more cost-effective regeneration method than seeded jack pine.

Table 6 summarizes the results of example 2 in which planted jack pine bare-root stock and containerized seedlings are compared on the basis of the benefit:cost ratio. The main differences between the two methods of planting jack pine are expressed in terms of the differences in the cost of site preparation, stand establishment and expected stocking. All other factors are assumed to be identical for the two regeneration systems as indicated in Table 2. Here, it is assumed that either of the two regeneration systems may be applied to a given site.

Line 2 of Table 6 indicates, for example, that there is a 10% chance that the benefit:cost ratio for planted jack pine bare-root stock will be 2.11 and that for planted jack pine containerized stock it will be 1.92. Similarly, line 3 of Table 6 indicates that there is a 20% chance that the benefit:cost

ratio for planted jack pine bare-root stock will be between 1.93 and 2.64, while that for planted jack pine containerized stock will be between 1.78 and 2.47. Table 6 as a whole indicates that there is more than a 60% chance that planted jack pine bare-root stock will be more economical than planted jack pine containerized stock, while there is less than a 40% chance that planted jack pine bare-root stock will be less economical than planted jack pine containerized stock on the basis of the input estimate and assumptions used for this example.

Table 6. Output of model "FIDME" for economic comparison of planted jack pine bare-root stock and containerized seedlings for a rotation age of 70 years, an interest rate of 10% and an inflation rate of 5%.

	Benefit:cost ratio	
Probability of exceeding	Planted jack pine bare-root	Planted jack pine containerized seedlings
0.00	2.64	2.47
0.10	2.11	1.92
0.20	1.93	1.78
0.30	1.78	1.68
0.40	1.68	1.58
0.50	1.57	1.50
0.60	1.44	1.42
0.70	1.27	1.35
0.80	1.15	1.28
0.90	0.96	1.17
1.00	0.38	0.64

Table 7 summarizes the results of example 3 in which three regeneration systems for planted jack pine and black spruce bare-root stock and planted white spruce containerized stock are compared on the basis of present net worth. As indicated in Table 3 the main differences in the three regeneration systems are expressed in terms of the cost of site preparation, the cost of stand establishment, expected stocking level, final yield and rotation ages. Differences in site productivity on the three sites are expressed mainly in terms of the final yield and rotation age. The results of this example may be used to rank the three sites for regeneration or to set priorities for the three investment alternatives.

Table 7 compares the three regeneration systems on the basis of present net worth. Line 2 of Table 7, for example, indicates that there is a 10% chance that present net worth/ha will exceed $444.29 for planted jack pine, $270.48 for planted black spruce and $473.65 for planted white spruce containerized stock, respectively. This table also indicates that there is a 50% chance that present

net worth/ha will be between $248.45 and $727.19 for planted jack pine bare-root stock, between $118.47 and $477.83 for planted black spruce bare-root stock and between $318.40 and $664.64 for planted white spruce containerized stock, respectively. It should be noted that where present net worth is positive, the investment is more attractive than the alternative rate of return by that amount per unit area. When present net worth is negative, the investment is less profitable than the alternative rate of return by that amount per unit area. For the above example, results indicate that there is less than a 20%, 30% and 10% chance, respectively, that these investments will be less profitable than the alternative rate of return. On the basis of the input estimates used and assumptions made for the third example, it may be concluded that, of the three regeneration systems compared, planted white spruce will be the most profitable investment followed by planted jack pine and black spruce.

Table 7. Output of model "FIDME" for economic comparison of three regeneration systems (planted jack pine and black spruce bare-root stock and planted white spruce containerized tree seedlings) based on the present net worth criterion, an interest rate of 12% and an inflation rate of 5%.

	Present net worth ($/ha)		
Probability of exceeding	Planted jack pine	Planted black spruce	Planted white spruce
0.00	727.19	477.83	664.64
0.10	444.29	270.48	473.65
0.20	377.52	231.25	426.37
0.30	330.28	205.53	388.67
0.40	289.47	152.89	358.54
0.50	248.45	118.47	318.40
0.60	217.96	83.42	282.21
0.70	167.19	25.00	250.79
0.80	109.79	-70.36	207.62
0.90	-11.94	-211.33	164.10
1.00	-1041.37	-935.62	-47.83

Results of the fourth and final example are summarized in Table 8. This table compares the three investment alternatives of planting jack pine for pulpwood and sawlog production, planting black spruce for pulpwood production, and planting Scots pine for Christmas tree production on the basis of internal rate of return. The main differences in the three forestry investments have been expressed not only in terms of the costs of site preparation, plantation establishment, expected stocking, final yield and rotation age, but also in terms of initial cost, annual, periodic and liquidation costs, and annual, periodic and terminal returns. Other differences have been expressed in terms of the number

and type of products, e.g., pulpwood versus pulpwood and sawlog, and Christmas tree production. Also, differences have been expressed in terms of the future price of different products from each investment. The results of the model application should provide a basis for ranking these three investments for the forest landowner.

Table 8 provides the expected rate of return from the three investments at a 10% probability interval. Line 2 of this table indicates, for example, that there is a 10% chance that the rate of return from planted jack pine will be between 12% and 13%, that from planted black spruce it will be about 11%, and that from planted Scots pine for Christmas tree production it will be between 20% and 22%. Conversely, it indicates that there is a 90% chance that the internal rate of return from planted jack pine will be between 11% and 12%, that from planted black spruce it will be between 8% and 11%, and that from planted Scots pine it will be between 17% and 20%. This table also indicates that the internal rate of return from planted Scots pine is 6% to 9% higher than that from planted jack pine and 9% to 11% higher than that from planted black spruce at most probability levels. Therefore, the task of ranking the three investment alternatives becomes fairly simple. Under the assumptions made and on the basis of the input estimates used for this example, planted Scots pine for Christmas tree production will be the most attractive investment followed by planted jack pine for pulpwood and sawlog production and planted black spruce for pulpwood production.

Table 8. Output of model "FIDME" for comparing the relative economic desirability of three forestry investments, namely, planted jack pine for pulpwood and lumber production, planted black spruce for pulpwood production and planted Scots pine for Christmas tree production on the basis of internal rate of return criterion.

Probability of exceeding	Internal rate of return		
	Planted jack pine	Planted black spruce	Planted Scots pine
0.00	0.13	0.11	0.22
0.10	0.12	0.11	0.20
0.20	0.12	0.11	0.20
0.30	0.12	0.10	0.20
0.40	0.12	0.10	0.19
0.50	0.12	0.10	0.19
0.60	0.12	0.10	0.19
0.70	0.12	0.10	0.18
0.80	0.12	0.10	0.18
0.90	0.12	0.09	0.18
1.00	0.11	0.08	0.17

MODEL SENSITIVITY

Numerous trial runs were conducted to examine the model sensitivity with respect to changes in various input estimates. The results of these trial runs may be summarized as follows:

1) The model is very sensitive to estimates of expected stocking levels in comparison with the stocking standards for all criteria. For example, if stocking standards are reduced by 10%, say from 65% to 55%, for all regeneration systems, the relative performance of the regeneration system with the lowest expected stocking level shows the most improvement and that with the highest expected stocking level results in the least improvement.

2) The model is quite sensitive to estimates of the final yield for all criteria and it is also sensitive to the estimates of future prices, except in the case of the cost-effectiveness criterion. That is, if the estimates of the final yield or product prices for all investments are changed by a constant amount, the regeneration system with the lowest yield or product price will be most affected.

3) The model is also quite sensitive to initial cost, i.e., land value, cost of site preparation and stand establishment, for all economic criteria. The timing and relative magnitude of these costs have considerable effect on the comparison of investments under consideration. For example, if the initial costs for all regeneration systems being compared are doubled, without affecting the final return and product prices, the regeneration system with the lowest initial cost will be most affected. However, if raising the initial cost by a given amount increases the expected stocking levels or reduces the rotation ages proportionately, the relative economic performance of the regeneration system with the lowest initial cost, or the lowest expected stocking level and/or the longest rotation age, will improve the most.

4) The model can be fairly sensitive to periodic costs and returns but this sensitivity is dependent on their relative magnitude and frequency of occurrence. If the periodic cost of fertilization or thinning results in the reduction of rotation age and/or increases the final yield for a regeneration system, it could become the factor most affecting the relative economic performance of such a regeneration system.

5) The model is somewhat insensitive to the estimates of annual costs and returns, mainly because of their relative magnitudes in comparison with other costs and returns. Annual costs and returns do not usually influence the final yield and product prices.

6) Finally, the model is least sensitive to the estimates of terminal costs and returns--mainly because of their relative magnitude and timing.

SUMMARY

The model described above contains significant improvements and modifications over its predecessor "REGEN". It allows comparison of any kind of long-term forestry investment consisting of a few to many types of costs and returns. It is mainly an interactive model which allows the use of either point or subjective estimates for nearly all inputs required. If properly used, the model should provide a valuable aid to forest managers in making rational economic decisions on various silvicultural investments--particularly those related to forest renewal. With the aid of this model, the forest manager may have the best chance of selecting the most economical regeneration system or, alternatively, he may choose the regeneration system that has the best chance of producing wood at the lowest future cost/unit volume.

Application of subjective probability estimates in this model has three purposes: 1) it serves as a built-in mechanism to adjust for the risk and uncertainty associated with the long-term investments under consideration; 2) it provides a simple method of utilizing limited data augmented by personal experience or feelings about future outcomes of a given set of conditions; and 3) it allows incorporation of variability and thus associated probability with the results.

A taped copy of the program listing and input examples may be obtained from the authors.

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